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ERGONOMICS IN THE DESIGN OF OFFICE FURNITURE

A REVIEW OF EUROPEAN LITERATURE

K. H. EBERHARD KROEMER, DR. ING.

JOAN C. ROBINETTE

JULY 1968

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Foreword

• This literature survey was initiated in 1965, when the first author was with Max-Planck Institute for Work Physiology, Dortmund, West Germany. The need for a review of the pertinent literature became apparent while he took part in the revision of the German Industrial Standard DIN 4549, Office Furniture. In 1966, he became a member of the Anthropology Branch, Human Engineering Division, of the Behavioral Sciences Laboratory. Based on a translation of the original German manuscript, the literature survey was enlarged to incorporate recent information. The report was completed during the Spring of 1968 in cooperation with Mrs. Joan C. Robinette, Scientific and Technical Information Officer of the Aerospace Medical Research Laboratories. The work supports Project 7184, "Human Performance in Advanced Systems;" Task 718408, "Anthropology for Design."

During the preparation of this report, valuable information, comments, and advice were given by Dr. R. Coermann, Chief, Biomechanical Department, and by Dr. G. Lehmann, Professor and Director, of the Max-Planck Institute for Work Physiology, Dortmund, West Germany; by Messrs. C. E. Clauser, Chief, Anthropology Branch, H. T. E. Hertzberg, Research Physical Anthropologist, and by Dr. M. J. Warrick, Assistant Chief, Human Engineering Division, of the Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio.

This technical report has been reviewed and is approved.

WALTER F. GRETHER, PhD
Technical Director
Behavioral Sciences Laboratory
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Abstract

This report discusses the European literature on "healthy" sitting postures and, relatedly, of suitable office and shop furniture, especially of chairs. Recommendations by orthopedists, physiologists, and physical anthropologists are summarized and tabulated for the height, shape, and dimensions of the seat surface; for the shape and dimensions of the back rest; and for the height of office desks, as well as for tables and stands to be used with office machines, such as typewriters. Researchers generally agreed that the trunk, including neck and shoulders, should be in a natural, upright, but relaxed position. The seated person must be able to select and change his body position from time to time. Weight transfer through the thighs should be avoided; body weight should be transmitted mainly through the buttocks. The height of the seat should be adjustable so the individual's feet can be placed firmly on the floor while the thighs remain horizontal. A back rest should be provided on all chairs to allow temporary relief of weight from the spinal column. Chair and desk (or table) should be treated as a unit and the height of the working surface should be derived from the height of the seat surface.

Section I.

INTRODUCTION

The body posture of sedentary workers, especially in offices, and of school children has long been a concern of orthopedists and physiologists. The increasing number of office positions, of seated factory workers, of people sitting in cars and airplanes, even of seated soldiers, has augmented the concern about "unhealthy" sitting postures. Complaints about lower back pains are widespread among people who commonly work in the sitting position.

Medical treatment of ailments thought to be connected with the sitting posture, sick leave taken by employees, and reduced work output highlight some of the economic aspects. Private industry and government agencies try to furnish well-designed chairs to their employees to keep them healthy on the job and to satisfy labor unions. Designing, manufacturing, and selling of ever "improved" office furniture, especially of chairs, provides many jobs.

To the authors' knowledge, no study has ever been conducted in Europe to determine a relationship between sitting posture and office furniture, and work attitude and work efficiency. During the 3rd International Congress on Ergonomics (Birmingham, England, September 1967), a session was held on "Ergonomics in Offices." Of all the papers given, only one dealt with the effects of office furniture on job efficiency; that paper was specially invited from a commercial U. S. business consultant (Fucigna, 1967).

It is extremely difficult to establish objective criteria for "healthy" sitting postures, consequently it is difficult to establish criteria for suitable furniture. Can the cause of a worker's degenerated and protruding intervertebral disk be linked to his job? Is a patient's back pain caused by his sitting posture and the furniture he uses at the job? Or does it result from age or personal activities? Can an increased work output of a secretary or manager be traced to using new chairs?

Still, there is no doubt that differences exist among sitting positions, that both poor and better furniture are available, and that there is a need to find the best, or at least the suitable. In Europe, this problem still is largely in the domain of medically trained specialists, orthopedists, and physiologists, as well as anatomists and physical anthropologists. Designers and engineers, trained in ergonomics, heavily rely on their findings.

This report reviews the European literature relevant to body posture of sitting persons and to the chairs, desks, and tables they use.

Section II.

BODY POSTURE AND FORM OF THE SPINAL COLUMN OF THE SEATED OPERATOR

The spinal column of a healthy man is straight in the front view and curved in profile: a lordosis (forward bend) at the neck, a kyphosis (backward bend) in the thorax, and another lordosis in the lumbar region. In the normal posture, there is an even distribution of pressure over the surfaces of the elastic intervertebral discs separating the bony vertebrae. Other curvatures of the spinal column, however, result in uneven pressure distribution along the intermediate discs, and hence, in their deformation.

The spinal column of healthy young persons is flexible and elastic. With increasing age, however, the intervertebral discs lose much of their firm elasticity. The lumbar discs seem to be exceptionally subject to degeneration. If the lordosis of the lumbar spine is flattened or even reversed to a kyphosis, softened lumbar discs may protrude posteriorly. Keegan (1962, p. 138) reported: "This gives rise to low back pain from ligament stretch, with difficulty straightening the back in rising, very common complaints in physically active persons past the youth age . . . Heavy stooping back strain, with excessive flattening of the lumbar curve, may cause rupture and extrusion of tissue from a degenerated disc. Back pain then is less, but compression of the (overlying) nerve root by the extruded tissue causes hip and leg pain . . . Recognition of this is very important for understanding of the problems of seating."

Among sitting postures, three different kinds may be distinguished and each of them associated with certain postures of the spinal column. The three postures of the trunk are called the anterior, the middle, and the posterior (Schoberth, 1962). These postures can be observed most easily in a subject sitting on a flat stool without a back rest, the height of the stool so adjusted that the thighs of the subject are about horizontal, his lower legs vertical and his feet flat on the floor. The three sitting postures are described by the location of the center of gravity of the body and also by the force (expressed in fractions of the total body weight) which is transmitted by the feet to the floor.

In the anterior position the trunk is bent forward. Consequently, the center of gravity of the torso falls in front of the ischial tuberosities, and the feet transmit more than one-fourth of the body weight to the floor. If the person sits relaxed, his lumbar spine is in kyphosis.

In the posterior position, the trunk is held upright or slightly inclined backward. The center of gravity is above or somewhat behind the tuberosities, and the feet carry less than one-fourth of the body weight. The lumbar spine is in lordosis if the muscles of the trunk are tightened. If sitting relaxed, however, generally kyphosis will be observed.

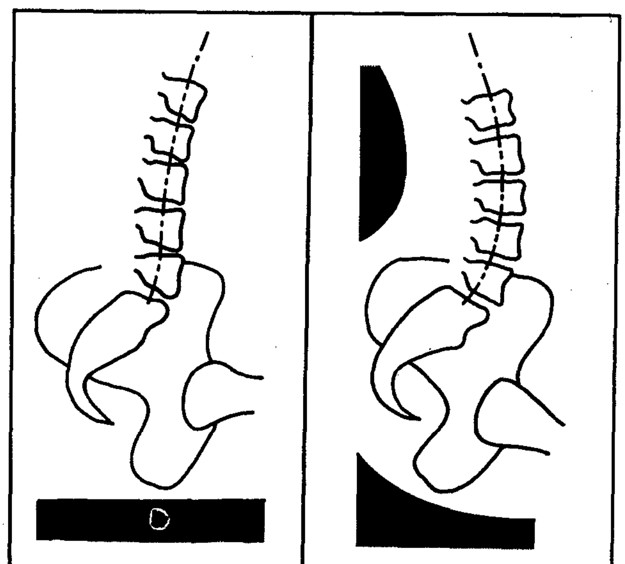
The middle position is, of course, intermediate between the anterior and the posterior postures. In this position, the trunk is held erect or bent forward slightly and the feet transmit about one-fourth of the body weight. In the middle position, the lumbar spine is either straight or lordotic. According to Schlegel (1956), maintaining the middle position requires continuous isometric tension of muscles and therefore can be sustained only for short periods of time. In some contrast to Schlegel's statement, Lundervold (1951) and Schoberth (1962) found only relatively little muscle activity involved.

Attaching a back rest to the stool and profiling the seat surface instead of leaving it flat and

horizontal will affect sitting habits. These means have been employed separately or combined in attempts to improve sitting postures; mainly, to attain a lordosis of the lumbar spine.

By leaning against a properly designed back rest, part of the body weight is taken off the spine and supported by the back rest. While this decreases the strain on the spinal column, the spine also adapts to the form of the back rest. If the back rest protrudes at the lumbar region, the lumbar spine is pushed into lordosis while the subject leans against the back rest. Back rest designs based on this idea were proposed in 1884 by Staffel, in 1913 by Strasser, and modified since 1948 by Åkerblom.

On a flat surface, the pelvis of a sitting person is rotated backward, the ischial tuberosities acting as points of rotation (figure 1). Since the lower end of the spinal column is connected to the pelvis by union of bones as well as by tendons and muscles, the posture of the spine, and specifically of its lumbar part, depends to some extent on the position of the pelvis. Rotating the pelvis backward results in a kyphosis of the lumbar spine, while a forward tilt of the pelvis generally leads to lordosis of the lumbar spine. Consequently, forward declining seat surfaces were proposed by Schlegel (1956); Schneider et al. (1961 a, b); and Schoberth (1962) to attain a lordosis of the lumbar spine.



Kyphosis while sitting without back rest. The pelvis is tilted backward on the flat seat surface.

Lordosis attained by lumbo-sacral back support. The pelvis is rotated forward on the profiled seat surface.

Figure 1: Kyphotic and Lordotic Postures of the Lumbar Spine

HOW TO DEFINE AND OBTAIN A "GOOD" SITTING POSTURE

Anthropometric data have been used as a basis for seat design (Barkla, 1961; Berkowitz, 1963; Grandjean and Burandt, 1962 b; Juergens, 1961, 1967; Kroemer, 1962 a, 1963, 1966; Peters, 1967; Ries, 1963; Wiesner and Rebiffé, 1963 a, b). Anatomists, orthopedists, and physiologists have tried to evaluate the essentials of a "good" sitting posture (Åkerblom, 1948, 1954, 1958; Bouisset and Monod, 1963; Burandt, 1963; Floyd and Roberts, 1958; Grandjean, 1963, 1965 a, b, 1967; Gschwend, 1965; Huc, 1952; Keegan, 1953, 1962; Lehmann, 1961, 1962; Lorenz, 1914; Lundervold, 1951, 1958; Mueller and Vetter, 1954; Ollefs, 1951; Schlegel, 1956, 1958; Schneider et al., 1961 a, b; Schoberth, 1962; Staffel, 1884; Strasser, 1913). Among them, reasonable agreement has been reached with respect to the interferences between trunk posture and form of the spinal column while sitting, as stated in the preceding section of this report.

Although the medically and anthropometrically oriented researchers pointed out main principles, their recommendations are not always concurring, and certainly not sufficient for either definition of "healthy" or "good" sitting postures, nor for establishing design standards for chairs.

In addition to the mainly theoretical considerations cited, field studies were conducted in which the postures of sitting people were observed (Branton and Grayson, 1967; Burandt and Grandjean, 1963, 1964; Floyd and Ward, 1965; Grandjean and Burandt, 1962; Karvonen et al., 1962; Langdon, 1965). These studies revealed interactions between posture, age, sex, and occupations of the observed people, and the design of chairs and desks.

It is reasonable to assume that the feeling of "comfort" is associated with a healthy sitting posture and a suitable seat. Hence comfort has been used as a criterion for posture and seat. Comfort contains many subjective feelings that make this term useful and, at the same time, difficult to objectify. No comprehensive definitions or criteria for comfort have been found yet. Its antonym, discomfort, apparently can be sensed by the subject and be described more easily. So comfort has been explained as the absence of discomfort (Hertzberg, 1958). An approach to objectifying comfort is to measure the duration of time a subject can sit without interruption, the underlying theory being that the longer the person can sit, the more comfortable the posture (the seat) must be. It has also been reasoned that the number and the amplitude of involuntary motions a subject performs while sitting indicate the degree of comfort: the less he moves, the more comfortable are posture and seat (Allen et al., 1959; Barkla, 1964; Chidsey, Shackel and Shipley, 1966; Coermann and Rieck, 1964; Grandjean et al., 1960; Hertzberg, 1958; Jones, 1966; Rieck, 1965; Wachsler and Learner, 1960; and Wotzka, 1966). Subjective ranking methods and measurements of motion frequency and amplitude have been employed simultaneously and used in addition to physiological and physical measurements (Schoberth, 1962). It has been shown, however, that comfort ranking of chairs by "experts" does not necessarily coincide nor agree with experimental results (Chidsey and Shackel, 1966).

Obviously, the sitting posture of a person depends not only on design and adjustment of the seat, but also on the individual's sitting habits and on the type of work he performs. If, for example, his hands must reach over a fairly large area and, in addition, exert considerable forces, this generally does not allow him to lean against the back rest. On the other hand, if the job requires only small-range effortless motions, use of the back rest is possible most of the time. Pilots or drivers provide extreme examples for determination of the body posture by the job; for extended periods of time, they must maintain a posterior position, enforced by vision requirements, arrangement of foot and hand-operated controls, and by restraining devices.

No such thing as "the" healthy sitting posture exists, and consequently, no chair "good" for all purposes will ever be designed. The appropriate posture for a young typist probably will be unsatisfactory for an elderly worker at an assembly line. Job requirements, age, subjective habits, and physical conditions of the sedentary worker may require quite different sitting postures.

Nevertheless, some general recommendations for the sitting postures, hence for furniture design, can be abstracted from the literature:

1. The trunk, including neck and shoulders, should be in a natural, upright, but relaxed posture. The spinal column should not be bent severely and, especially, kyphosis of the lumbar spine should be avoided.

2. The seated person must be able to choose and change his body posture. No body posture can be maintained indefinitely, as even the most comfortable position becomes unbearable after some time. Enforced posture generally occurs if the head (eyes) or the hands or feet (controls) must be kept in certain positions, or if the seat surface is small or distinctly shaped.

3. The body weight should be transmitted to the seat surface mainly through the buttocks. Weight transfer through the thighs should be avoided. The surface of the seat should have flat upholstery in order to distribute the pressure.

4. A back rest should be provided so that the sitting person can lean back temporarily at least. This enables him to relieve some weight from the spinal column.

5. The height of the seat should be adjusted so that both feet can be placed firmly on the floor while the thighs are horizontal. The angle between thighs and trunk should be greater than 90 degrees.

Section III.

THE CHAIR

Most of the chairs used by secretaries and typists, and chairs used by operators in factories and assembly lines fall in the same category: small to medium-sized, with a back rest, but without arm rests, adjustable height, and relatively inexpensive. All of these chairs have in common that they are used "on the job." Such seats, in the broadest sense, are properly designed if they facilitate the job.

The following considerations concern this type of chair only. It is in common use all over Europe and is considered there as a necessary piece of equipment. Fortunately, it is also the type of chair that "represents the nearest approach to the correct seat" (Keegan, 1962, page 141).

To compare European recommendations for the design of chairs with recommendations published in the U.S.A., instructive reviews by Damon, Stoudt, and McFarland (1966) and by the National Swedish Institute for Building Research (1965) are available.

Figure 2 indicates the principal parts, dimensions, and adjustments of the standard seat. Details are discussed in the subsequent paragraphs.

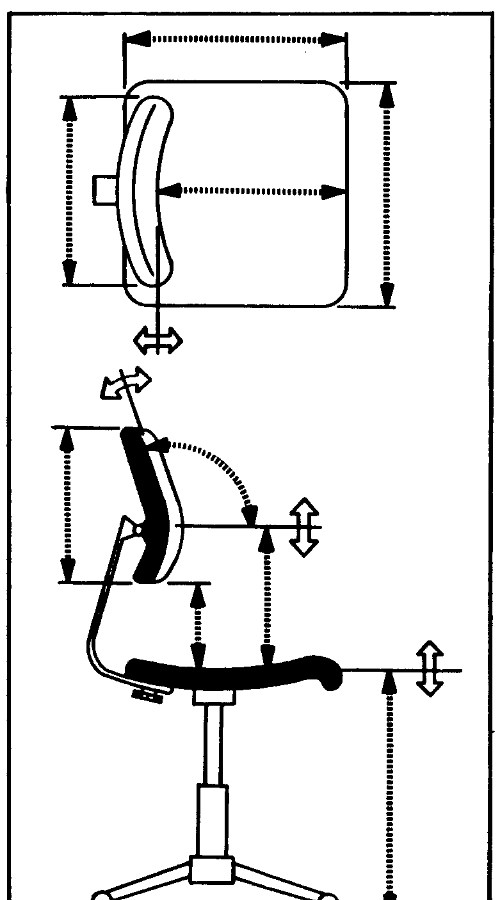


Figure 2: Principal Dimensions and Adjustments of a Chair

THE HEIGHT OF THE SEAT SURFACE

The height of the seat surface is adjusted correctly if the thighs of the sitting individual are horizontal, the lower legs vertical, and the feet flat on the floor. In other words, the height of the seat should be slightly less that the distance from the floor to the popliteal area of the seated individual. As this distance varies considerably between different persons, the seat must be adjustable so that each person can choose the proper height. (Seat heights can be discriminated extremely well, as Kirk and coworkers (1967) found in a laboratory study.) If the individual chooses the correct height, he can sit fully on the entire surface and still may shift his buttocks if he wants to change his position. At the same time, relaxing flexion or extension of the legs is facilitated. By displacing the feet, blunt angles between the trunk and the thighs can be achieved, as recommended by Keegan (1962). Still, the seated individual will not suffer from pressure between the undersides of the thighs and the edge of the seat.

Pressure from the edge of the seat is distinctly uncomfortable because the soft undersides of the thighs are not qualified for sustained compression. If the seat is too high, such pressure is always present, even if the front ridge of the seat surface is well rounded or upholstered. To avoid such compression, people tend to sit on the front portion of a high seat. While this leads to the desirable angle of more than 90 degrees between the thighs and the trunk, it also causes an unstable and fatiguing posture, requiring static contraction of muscles to be maintained.

Compression of the thighs will certainly be eliminated if a low seat is used. However, if an individual sits on a chair that is too low, a more acute angle between his thighs and the trunk is likely to occur. This acute angle causes an unfavorable relative position of pelvis and spinal column, and also causes pressure on the abdominal organs. Tall, heavy, and elderly people often find it difficult to get up from a low chair.

Table I gives the recommendations for the height of the seat surface as found in the literature. (In this table, as in the following ones, the data of the most recent or the most detailed publication are cited if the same author has published several articles containing the same information.)

Åkerblom (1948, 1954, 1958), Lehmann and Stier (1961), and Stier (1959) recommended relatively low chairs. Their basic idea was that low seats, appropriate for medium-sized and small people, should be used since tall people would not have any difficulties sitting on these chairs. In contrast, Burandt (1963, 1964), and Grandjean (1963, 1964, 1965, 1967), as well as Schoberth (1962) focus on tall people. They recommended high chairs. Short people have to use foot rests.*

The recommendations about the "effective seat height," that is, the vertical distance between the seat and the floor or the foot rest, respectively, are fairly concurrent, as table I shows. All authors recommended that the seat height be adjustable.

THE SHAPE OF THE SEAT SURFACE

In rare cases, extreme profiling of the seat may be necessary and subjectively comfortable. In general, however, distinctive shapes of the seat surface limit the number of possible variations of the sitting posture. Lehmann (1961) claimed one of the most important features of a good chair be that it facilitates changing the posture. He pointed out that even the most comfortable position becomes more and more uncomfortable and eventually unbearable.

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*Foot rests should have a fairly large surface so that the seated person can place his feet in various positions on it. Vertical bars or other small rests confine the feet to certain positions and don't allow sufficient muscle relaxation.

TABLE I.

RECOMMENDED HEIGHTS FOR THE SEAT SURFACE

Reference	*Height—cm*	*Remarks*
Akerblom 1948, 1954, 1958	About 40	Dimensions derived from small people.
Arbeidsinspectie 1961	42-52 (OP† and SEC ‡)	———
Berglund, 1957 cit. after Binkhorst 1961	43-44	Dimensions derived from medium-sized people.
Burandt 1964*	45-53 (SEC)	To be used at 78 cm desks, foot rests up to 10 cm may be necessary.
	40-48 (SEC)	To be used at 72 cm desks, foot rests up to 5 cm may be necessary.
Enzmann 1958	About 45, adjustable between 44 and 54 (SEC and OP)	Dimensions derived from very short and very tall people. 72 cm desks recommended. Use of foot rests proposed.
Floyd and Roberts, 1958; Floyd and Ward, 1965	Theoretically 38-48, practically 43-46 (SEC)	69-71 cm desks recommended.
Grandjean 1963, 1964, 1965, 1967	40-53 (SEC and OP)	70-78 cm desks recommended. Dimensions derived from tall people. Foot rests necessary for short people.
Huc 1952	45 (OP)	———
Keegan 1962	41-46 (SEC)	USA
Kroemer 1963, 1966, 1967	41-49 (SEC and OP)	72-75 cm desks recommended.
Laisz and Wuensch 1964 a, b, c	37-59 (OP)	Foot rests often necessary.
Lehmann and Stier 1961	40-43 (SEC and OP)	Dimensions derived from small to medium-sized people. 70-75 cm desks recommended.
Murrell 1965	35-45 (OP)	———
Schoberth 1962	45-48 (SEC and OP)	78-80 cm height of manual area or desk. Foot rests necessary.
Stier 1959	40-43 (SEC and OP)	75 cm desks recommended.
Stoll 1960	45-53 (SEC)	To be used at 78 cm desks. Foot rests up to 14 cm necessary.
	39-46 (SEC)	To be used at 68-75 cm desks.

*The same recommendations in Burandt and Grandjean, 1963; and Grandjean and Burandt, 1962a.
†(OP): Operator chair in factories and shops
‡(SEC): Secretary and typist chair

The position of the pelvis determines to some extent the posture of the spinal column, as previously discussed. In order to rotate the pelvis forward and so to attain a lordosis of the lumbar spine (fig. 1), Staffel (1884) and Schlegel (1956, 1958) suggested that the entire seat surface be tilted downward. Such a slope can tilt the pelvis forward, but it also causes the body to slide forward. The forward thrust must be counterbalanced by action of the leg muscles, which in turn becomes uncomfortable and fatiguing. Instead of tilting the total surface, Schneider and Decker (1961) and Schneider and Lippert (1961) proposed an elevation of about 30 degrees of the rear portion of the seat, leaving the front part approximately horizontal. The inventors argued that, while sitting on the so-called Schneider-Wedge, the pelvis would be tilted forward. They claimed that this device eased pain in the back, neck, and shoulder-arm region in many of 200 patients. Yet, Schoberth (1962) questioned whether the Schneider-Wedge could fulfill all expectations. Burandt and Grandjean (1964, 1965) conducted experiments with 52 healthy subjects and found that an elevation of the rear portion of the seat does not necessarily cause lordosis of the lumbar spine in healthy subjects. Their test subjects generally preferred a flat surface to an inclined one.

As table II indicates, a slight rearward slope of the entire seat surface is proposed by some authors. This declination is supposed to tilt the trunk toward the back rest and, at the same time, prevent forward slipping of the bottocks. Unfortunately, many persons do not lean against the back rest during work, consequently, a distinct rearward slope of the seat tends to rotate the pelvis backwards, causing kyphosis of the lumbar spine.

Presumably, pronounced slopes of the seat surface are unsatisfactory, whether they are to the front or to the rear, as they enforce certain postures. Thus a generally horizontal seat having a slightly concave curvature in the center appears to be most suitable. This concavity facilitates sitting in the center of the seat, prevents the buttocks from slipping off and still permits various postures.

Upholstery for the seat is generally recommended. On a hard surface, the weight of the trunk is transmitted to the seat through small areas. This causes high local pressure, resulting in diminished blood flow, numbness, and even pain (Coermann and Rieck, 1964; Floyd and Roberts, 1958; Hertzberg, 1958; Huc, 1952; Lehmann, 1961, 1962; Mueller and Vetter, 1954; Ollefs, 1951; Schoberth, 1962). Upholstery enlarges the load-bearing area and consequently reduces pressure.

The upholstery should not be too soft. The buttocks and thighs sink deeply into soft materials. Thus, all areas of the body that can contact the seat are already fully compressed, and no portions remain for the seated individual to adjust his position to gain relief from the pressure. In addition, the body often "floats" on soft upholstery, and the posture must be stabilized by muscle contraction.

A flat, stiff upholstery that gives way only a few centimeters under the weight of the body is frequently recommended. Using such material, the pressure-loaded area is sufficiently enlarged and the posture may be altered easily. Experiments on the effects of seat cover materials on pressure, temperature, sweat production, etc., were conducted by Burandt and Grandjean (1966).

Obviously, the seat surface should have no sharp or hard edges. Special attention should be paid to the front edge of the seat, which must be well rounded and upholstered so that no excessive pressure is applied to the underside of the thighs.

TABLE II.

RECOMMENDATIONS FOR THE SHAPE OF THE SEAT SURFACE

Reference	*Slope*	*General Shape*
Akerblom 1948, 1954, 1958	3-5 degrees rearward.	Slightly concave.
Arbeidsinspectie 1961	3 degrees rearward of the front portion only (OP † and SEC ‡)	Concave, radius about 85 cm.
Association des Industriels de Belgique, 1960	------	Slightly profiled, possibly saddle-like (OP).
Burandt 1963, 1964	3 degrees rearward of the front portion only; for some, a slight forward declination of the entire seat (SEC).	No distinct profile. Slightly concave according to the buttock-thigh contour.
Floyd and Roberts 1958	Horizontal; for some, a rearward declination of up to 5 degrees of the front part only (SEC).	No profile.
Grandjean 1963, 1964, 1965	3 degrees rearward (SEC and OP).	Normally no profile.
Huc 1952	Horizontal (OP).	Flat, upholstered, or with a cushion.
Keegan 1962	3 degrees rearward (SEC).	Slightly concave by means of upholstery.
Kroemer 1962 a	Horizontal to 7 degrees rearward (OP).	No distinct profile.
Laisz and Wuensch 1964 a, b, c	Up to 5 degrees rearward (OP).	------
Lehmann 1961, 1962	5-7 degrees rearward (SEC and OP).	No distinct profile.
Ollefs 1951	None to 5 degrees rearward.	Slope only if back rest is inclined.
Schlegel 1956, 1958	Adjustable forward declination.	Especially for people suffering from pains in the hip and back region.
Schneider et al 1961 a, b	------	A "wedge" at the rear end, inclining about 30 degrees. Wedge attached to the back rest if back angle is variable. Front part of the seat essentially horizontal, slightly concave.
Stier 1959	Up to 7 degrees rearward (SEC and OP).	------

†OP: Operator chair in factories and shops
‡SEC: Secretary and typist chair

TABLE III.

RECOMMENDATIONS FOR SURFACE DIMENSIONS OF THE SEAT

Reference	*Length (Depth) cm*	*Breadth cm*	*Type**
Åkerblom 1948, 1954, 1958	About 40	-----	SEC
Arbeidsinspectie 1961	38-40	Minimum 38	OP
Ass. d. Industr. de Belgique, 1960	About 40	About 40	OP
Burandt 1964	About 40	Minimum 40	SEC
Floyd and Roberts 1958	About 38	About 41	SEC
Grandjean, 1963; Grandjean and Burandt, 1962 a	32-40	-----	SEC and OP
Grandjean 1967	Minimum 35	-----	SEC
Huc 1952	About 40	About 40	OP
Keegan 1962	36	-----	SEC
Kroemer 1962 a	35-40	35-40	SEC and OP
Laisz and Wuensch 1964 a, b, c	35-40	35-40	OP
Lehmann 1961	30-40	-----	SEC and OP
Murrell 1965	38-41	About 43	OP
Schoberth 1962	About 40, max. 42	About 43	SEC and OP
Stier 1959	35-40	35-40	SEC and OP

*SEC: Secretary and typist chair
OP: Operator chair in factories and shops

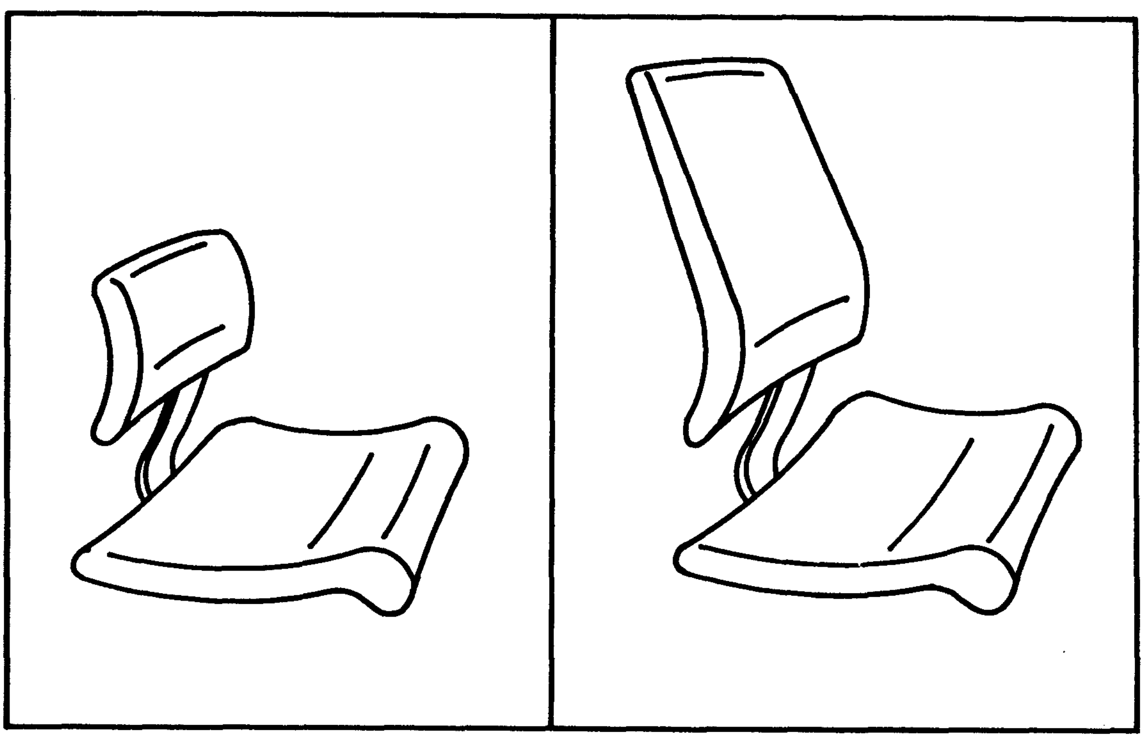
DIMENSIONS OF THE SEAT SURFACE

Breadth and length of the seat surface must be sufficient to accommodate large people and to facilitate changes of posture. This demand sets certain minimum requirements as shown in table III. While the seat may be as broad as reasonable, the length (front to back) of the seat must not be excessive. If the seat is too long an individual tends to sit only on the front part to avoid pressure on his thighs near the knees. Consequently, he will not use the back rest.

Length of the seat surface itself must be distinguished from the "sit-in depth," that is the horizontal distance between the front edge of the seat and the foremost part of the back rest. This distance should be a little shorter than the seat surface.

THE BACK REST

All chairs should have well-designed back rests, even if they are used only intermittently to relax during a break. Table IV summarizes design recommendations. Just above the seat surface, the back rest should either have an open space or recede so that the sacrum can be pushed back and lumbar contact made with the rest. If free mobility of the shoulders and arms is necessary (as, for example, while typing), only the lower part of the back can contact the back rest. A lumbar back support (LBS) can be provided by a small back rest (fig. 3), the upper edge of which is not more than about 35 cm and the lower edge approximately 12 cm above the seat surface. When



Lumbar Back Support LBS

Full-sized Back Rest FBR

Figure 3: Back Rests that Support either the Lumbar Area or the Entire Back

TABLE IV.
RECOMMENDATIONS FOR SHAPE AND DIMENSIONS OF BACK RESTS

Reference	*Type**	*Remarks*
Åkerblom 1948, 1954, 1958	FBR SEC	Back rest up to the shoulder. Lumbar pad 18-20 cm above seat. Upper part of the rest about 115 degrees inclined.
Arbeidsinspectie 1961	LBS OP SEC	Tiltable about a horizontal axis in the center of the back rest. Axis adjustable from 20 to 30 cm above seat. Horizontal depth from front edge of the seat adjustable between 36 and 46 cm. Dimensions: 30 by 16 cm.
Burandt 1963, 1964	LBS SEC	Slightly convex in the side view. Attached to the seat by a hard spring. Lower edge 14 cm, min. 10 cm, upper edge 36 cm, max. 40 cm above seat. Height adjustable. Should adjust to back contour. Horizontal depth from front edge of the seat adjustable from 34 to 44 cm. Dimensions: max. 37 by 20 cm.
Floyd and Roberts 1958	LBS SEC	Shape essentially as proposed by Åkerblom. Lower edge 20 cm. upper edge max. 33 cm above seat. Back rest attached to the seat by a strong spring.
Grandjean 1963, 1967 Grandjean and Burandt 1962 a	LBS SEC OP	Lumbar pad at about one-quarter of the height of the back rest; adjustable from 14 to 24 cm above the seat. Back rest tiltable from 90 to 120 degrees about a horizontal axis at the height of the pad. Minimum clearance between back rest and seat 12 cm. Horizontal depth from front edge of the seat adjustable from 34 to 44 cm. Dimensions: 32 (max.) by 20 cm.
Huc 1952	OP	Back rest inclined 105-120 degrees.
Keegan 1962	LBS SEC	Slightly convex in the side view. Inclined by 105 degrees. Lower edge 13 cm, upper edge 33 cm above seat.
Kroemer 1962 a	FBR SEC OP	Shape as recommended by Åkerblom. Spring attachment to the seat should not be too soft.
Laisz and Wuensch 1964 a, b, c	LBS OP	Lower part of the back rest about vertical, inclination of the upper part 100-110 degrees, beginning about 18 to 20 cm above the seat.
Lehmann 1961, 1962	FBR SEC OP	Shape as recommended by Åkerblom. Overall inclination 110-115 degrees. Tiltable about a horizontal axis. Height adjustable. Spring attachment to the seat should not be too soft.
Murrell 1965	LBS OP	Tiltable about a horizontal central axis. Clearance above seat surface about 20 cm. Dimensions: 18-20 by (max.) 33 cm. If FBR, then as proposed by Åkerblom.
Schneider and Decker 1961 Schneider and Lippert 1962	———	No "abnormal bends."
Schoberth 1962	FBR SEC	Shape as recommended by Åkerblom. Lumbar pad 16-20 cm above seat. Clearance between back rest and seat 14 cm. Upper part of the back rest 104-110 degrees inclined.
Stier 1959	FBR SEC OP	Shape as proposed by Åkerblom.

*FBR: Full-sized back rest
LBS: Lumbar back support (See fig. 3)
SEC: Secretary and typist chair
OP: Operator chair used in factories and shops

leaning against an LBS, support is given at the lumbar spine. The forward thrust, provided by the LBS, facilitates the desired lordosis of the lumbar column. Such a forward thrust can also be provided with a full-sized back rest (FBR), as shown in figure 3 on the right, if properly designed. For support of the lumbar region, the FBR must protrude anteriorly at the lumbosacral junction. This convex area has come to be known as the "lumbar pad" or "Åkerblom-bend." A well-designed FBR gives the desired lumbar support if the sitting person leans against it only slightly. During a break, however, he can lean back completely and relax comfortably.

Back rests, especially of the LBS type, are often attached to the seat elastically and give a certain distance when leaned against. A slight elasticity is quite pleasant. Considerable play, however, of more than about 2 cm, is undesirable. A softly hinged back rest gives firm support only when leaned against heavily; when leaned against only slightly, the reaction force provided by the back rest is not strong enough to hold the body, and a labile equilibrium must be maintained by muscle tension.

As early as 1914 Strasser proposed a lumbar back support with a horizontal axis at lumbar height. This back rest could tilt about that axis. The idea is that the surface of this back rest can adjust automatically to the contour of the back whether the sacrum or the upper part of the back is pushed farther back. Such a back rest may be comfortable, but it should not swivel so easily that the support is wobbly.

The edges of the back rest, especially at bottom and top, should be carefully rounded and well padded. This prevents painful pressure and facilitates alterations of posture.

ARM RESTS

If free mobility of the trunk, shoulders, and arms is required, arm rests would often be hindering. Arm rests, if feasible, may be used for propping the arms for a while, supporting part of the weight of the trunk and thus decreasing the load on the spinal column. They may also be helpful in changing position or as an aid in getting up from the chair. In some cases, arm rests may be only a status symbol.

Section IV.

THE DESK

In contrast to the theoretical recommendation that the height of the chair should correspond to the individual's leg dimensions, surveys showed that in practice the seat height is adjusted to the height of the desk (Floyd and Roberts, 1958; Floyd and Ward, 1965; Grandjean and Burandt, 1962 a; Kroemer, 1963, 1966; Langdon, 1965). In other words, chairs are really being adjusted to the height of the working surface; comfort of the hands, arms, shoulders, and eyes plays a more important role than comfort of the legs. This frequently causes rather undesirable positions of the trunk and legs and may greatly contribute to the pains and aches reported from sedentary workers (Burandt and Grandjean, 1963; Grandjean and Burandt, 1962 a; Koskela, 1962; Schleisner and Wedebye, 1961).

This finding leads to a simple conclusion. Chair and desk (or table) must be regarded as a unit. The height of the desk must be derived from the height of the chair. The height of the chair must correspond to the length of the lower leg. (This axiom implies that a footrest normally should not be necessary.)

For factory work, at assembly lines, etc., the elevation of the working area of the hands is difficult to define generally. It depends on the type of work performed, on the requirements for range of motion and on force exertion. Often, the work is performed quite a distance above the surface of table or bench. Consequently, only rough figures for the height of work benches or tables can be given (Daenzer, 1958; Enzmann, 1958; Grandjean, 1963, 1965 a, b; Kroemer, 1962 b; Laisz and Wuensch, 1964 a, b, c; Lehmann, 1961, 1962; Lehmann and Stier, 1961).

In the office, however, the hands perform generally at desk height. The surface of a desk (or the keyboard of a typewriter) should be about elbow height. This offers a comparatively simple basis for calculations. So it is not surprising that a large number of recommendations for the height of office desks have been published. They are compiled in table V. The authors based their suggestions on the desired body posture and, consequently, on the height of the seat surface and on body dimensions.

Authors recommending relatively high desks want to accommodate them principally to tall people, especially to males. They point out that smaller employees would have to use foot rests. Those authors who, on the other hand, try to avoid extensive use of foot rests by recommending lower desks, have to take into account that the free space under the desks ("leg room") must be ample enough to accommodate even very tall people. Despite these different approaches the vertical distance between seat and desk height, recommended by both groups of authors, varies only a few centimeters.

Incidentally, the height of almost all office desks manufactured in Europe falls within the range from 71 to 78 cm. Standards for office furniture do not exist in all countries. British Standard 3893 recommends that desks for clerks range from 71 to 74 cm (28 to 29 in), to be used with chairs of 43 cm (17 in). The 1967 revised West German Industry Standard DIN 4549 does not specify chairs (which generally are adjustable), but recommends desks of 75 cm (78 cm from 1936 to 1967) and typewriter tables of 65 cm (previously 68 cm).

STANDS, TABLES, AND DESKS FOR OFFICE MACHINES

The body postures of typists, teletypists, or operators of desk calculators, card punches, etc., are rather fixed. The workers have to keep their hands at the keyboard, their eyes have to be directed at certain targets, and sometimes a foot has to be kept on a control. All this enforces a rather uniform position of the hands, arms, shoulders, head, and trunk and does not leave much room for variations. Consequently, achieving a "correct" posture by appropriate use of suitable equipment is highly important. The operator's trunk should be effortlessly upright, in about the "middle position" described in Section II. The upper arms should hang down vertically, the forearms and the palms of the hands should be about horizontal (Burandt, 1963; Floyd and Roberts, 1958; Lehmann, 1961; Lundervold, 1951, 1958; Scherrer, 1967). There are some indications that unfavorable positions of the trunk, neck and head, as well as the shoulders, arms, and hands contribute to pain and troubles in the hand-wrist-forearm region, of which typists complain frequently (Kroemer, 1964 a, 1965 a, b). Figure 4 shows a typical posture of a typist.

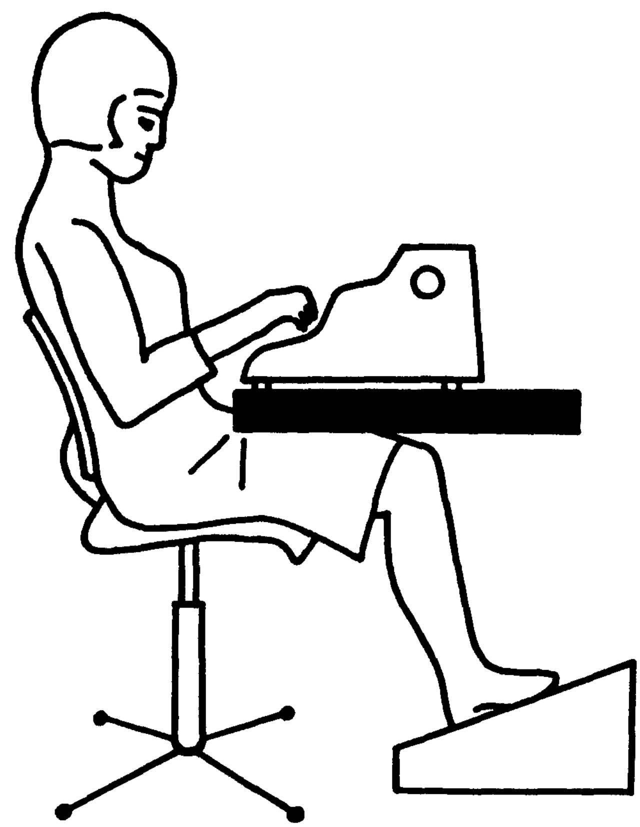


Figure 4: Typical Posture of a Typist

Although correctly using an adjustable chair and a foot rest, the large vertical distance between the underside of the table and the keyboard forces the typist to maintain an awkward posture.

Note: Compression of the thighs, curvature of the spinal column, elevation of the forearms.

To achieve a suitable sitting posture, the following conditions must apply:

1. The height of the chair is adjustable to the length of the operator's lower leg;
2. The height of the keyboard, i.e., the height of the table (stand) is adjustable;
3. The vertical distance between the keyboard and the underside of the table (stand) is very small.*

The correct keyboard height (and derived heights of tables and stands) can be estimated using body dimensions of the operators. This has been done by Kroemer (1963, 1964 b) for Germans. He recommended an average height of the seat of 45 cm, with a standard deviation (SD_1) of about 2 cm. The mean vertical elevation of the elbows above the seat was assumed to be 24 cm (SD_2 approx. 2.5 cm). The sum of both means gives the average height of the elbows above the floor, 69 cm. The standard deviation (SD) around a sum of means can be calculated from the formula

$$(SD)^2 = (SD_1)^2 + (SD_2)^2 + 2 \text{ x } K \text{ x } SD_1 \text{ x } SD_2$$

where K is the coefficient of correlation between the measures. According to the literature (Anthropology Branch, Aerospace Medical Research Laboratories, 1968; Enzmann, 1958; Hooton, 1945; Kroemer, 1966), K may here be assumed to be zero. Hence, SD of the sum is about 3 cm.

Using these data, the height of the keyboard (of the elbows) above the floor should range from 63 to 75 cm (mean $\pm$ 2 SD, to accommodate about 95% of the population). Still, this does not give the height of the table or desk upon which the typewriter or desk calculator is placed: The height of the keyboard above the standing surface has to be deducted. Subtracting 9 cm as the most frequently found distance, the surface of stands, tables and desks for office machines should be adjustable between 54 and 66 cm.

Trying to keep the keyboard as low as possible, one has to make sure that the operator has enough room for his legs. The upper side of the thighs should not be compressed, the operator should be able to move his feet forward and sideways to change his body posture. For minimum thigh clearance, Grandjean (1963) recommended that 12% of the individual knee height be added to the seat height and (1967) specified 61 cm for female and 64 cm for male Swiss employees; Burandt (1964) proposed 13 cm and Enzmann (1958) 12 cm to be added to the height of the chair.

Table V summarizes recommendations for the height of office desks, and of tables or stands for typewriters. To facilitate comparisons, the corresponding heights of the seat surface are also tabulated.

*Chairs with adjustable height are in common use in Europe. Adjustable tables or stands are rare but could be used in greater numbers. The vertical distance between the underside of the table and the keyboard usually is much too large, ranging from 10 to 20 cm. To reduce this distance substantially, Kroemer (1965a) proposed that office machines be fabricated with fasteners at their sides so that they could be hooked into openings in the surface of tables or stands instead of being placed upon them. Thus the keyboard would be lowered at least by the thickness of the table top and the height of the feet of the machine. By proper construction of machine and stand, the keyboard might be very little above the thighs of the operator. This would allow him to have the keyboard at elbow height and to work with his upper arms being about vertical, and his forearms and hands held horizontally.

TABLE V.

RECOMMENDED HEIGHTS FOR DESKS, STANDS, TABLES, AND TYPEWRITER DESKS

	Desk	Stands, Tables, and Typewriter Desks	Corresponding Seat Height
Reference	*Height of the surface above the floor – cm*		
Akerblom 1948, 1954, 1958	68-70	About 60 (Cit. after Binkhorst 1961)	About 40
Berglund 1957 (Cit. after Binkhorst 1961)	72	65	43-44
Bundesminist. f. Arbeit (1964)	—	58, adjustable in steps of 2 cm upward	—
Burandt 1964	76-78	—	45-53, foot rest may be necessary
	Min. 70, theoretically adjustable between 68 and 78	65 for females, 68 for males, theoretically adjustable between 53 and 70	40-48, foot rest may be necessary
Enzmann 1958	72	—	About 45, adjustable between 44 and 54
Floyd and Roberts 1958 Floyd and Ward 1965	69-71	61-64	43-46, theoretically 38-48
Grandjean 1965, 1967	70-78	65 for females 68 for males	40-53 (1967); foot rest may be necessary
Kroemer 1963, 1966	72, max. 75	Adjustable between 54 and 66	41-49
Lehmann and Stier 1961	70-75	About 65	40-43
Schoberth 1962	78-80	—	45-48, foot rest necessary
Stier 1959	75	65	40-43
Stoll 1960	78	—	45-53, foot rest necessary
	68-75	—	39-46

Section V.

SUMMARY OF RECOMMENDATIONS

In Europe, the problems of healthy sitting postures and, relatedly, of suitable furniture (mainly chairs) are in the domain of orthopedists, physiologists, anatomists, and physical anthropologists. Furniture designers heavily rely on their findings. Although many specific topics are still being studied, researchers generally agree on the following recommendations:

1. The trunk, including neck and shoulders, should be in a natural, upright but relaxed position. The spinal column should not be bent severely. Especially kyphosis of the lumbar spine should be avoided.

2. The seated persons must be able to choose and change his body posture. No body posture can be maintained indefinitely, as even the most comfortable position becomes unbearable after some time. Enforced posture generally occurs if the head (eyes) or the hands or feet (controls) must be kept in certain positions, or if the seat surface is very small or distinctly shaped.

3. The body weight should be transmitted to the seat surface mainly through the buttocks. Weight transfer through the thighs should be avoided. The surface of the seat should be cushioned to distribute the weight.

4. A back rest should be provided so that the sitting person can lean back temporarily at least, thus relieving some weight from his spinal column.

5. The height of the seat should be individually adjusted so that both feet can be placed firmly on the floor while the thighs are horizontal. The angle between thighs and trunk should be greater than 90 degrees.

6. Chair and desk (or table, stand, etc.) should be treated as a unit. The height of the desk should be derived from the height of the seat surface.

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13. ABSTRACT

This report discusses the European literature on "healthy" sitting postures and, relatedly, of suitable office and shop furniture, especially of chairs. Recommendations by orthopedists, physiologists, and physical anthropologists are summarized and tabulated for the height, shape, and dimensions of the seat surface; for the shape and dimensions of the back rest; and for the height of office desks, as well as for tables and stands to be used with office machines, such as typewriters. Researchers generally agreed that the trunk, including neck and shoulders, should be in a natural, upright, but relaxed position. The seated person must be able to select and change his body position from time to time. Weight transfer through the thighs should be avoided; body weight should be transmitted mainly through the buttocks. The height of the seat should be adjustable so the individual's feet can be placed firmly on the floor, while the thighs remain horizontal. A back rest should be provided on all chairs to allow temporary relief of weight from the spinal column. Chair and desk (or table) should be treated as a unit and the height of the working surface should be derived from the height of the seat surface.

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